A Study of the Structure of the Near-Coastal Zone Water Column Using Numerical Simulations

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LONG-TERM GOAL

Our long-term goal is to understand how flows in near-coastal zone (20m to 100m) respond to a variety of forcing mechanisms including tidal pressure gradients, surface waves, surface heating and cooling, surface wave-bottom current interaction, and tidally generated bottom boundary currents. Because the nature of this response varies throughout the water column and depends strongly on the non-linear coupling of stratification, turbulence and flow structure characterizing the structure of the water column in this environment is a very difficult field measurement task.

OBJECTIVES

It is possible to gain some insight into the physics, and into our ability to model or parameterize the physics, by looking at a more idealized version of this problem using a variety of numerical simulation approaches. We will perform large eddy numerical simulations of the mixing processes in the upper layer of the near-coastal, and deeper, using a periodic channel as the computational domain. Benefits of using numerical simulations, as compared to laboratory or field experiments, is the relative ease with which information about the turbulence can be extracted from the flow and the control over the external variables. The study has two fundamental goals: (1) Developing deeper understanding of the interaction between various physical mechanisms that affect the dynamics of the upper mixed layer in the near-coastal ocean and the deep ocean; and (2) Developing improved parameterizations of these processes for use in large eddy simulations (LES) and Reynolds-Averaged Navier-Stokes (RANS) models to be used in modeling on the larger scales.

APPROACH

Large eddy simulations (LES) will be employed to solve the Navier-Stokes equations for the turbulent channel flow numerically. The code that will be used in this study is based on one developed by Garg (1996). This code, which was originally developed and implemented on the 400 node Intel Paragon XP/S supercomputer at SDSC by Garg et al. (1994, 1995), is currently being modified to account for the additional physical phenomena we wish to include in our proposed simulations, such as Langmuir circulations. In this regard we will rely heavily on the recent work of Zhou (1999). Each improvement will be validated against basic test cases. The specific tasks are as follows: (1) to increase the Reynolds number of the flow; (2) to add Craik-Leibovich vortex forcing, to allow simulation of Langmuir circulations; and (3) to add a depth-dependent heat source, in order to simulate radiative heating and cooling.

For the turbulent cases, we used a large eddy simulation approach that models the sub-grid stresses with a dynamically determined Smagorinsky constant.We are currently using the dynamic eddy viscosity model of Germano et al (1991) with Lilly's (1992) least squares modification. More recently, attention has been focussed on velocity estimation or deconvolution models (Shah and Ferziger, 1995; Domaradzki and Saiki, 1997, and others). In this approach, an attempt is made to estimate the subgrid scale velocity field from the resolved field and to use that estimate to predict the behavior of the small scales of the turbulence. Our group (Katopodes et al, 2000) has recently developed such a model that is much simpler and cheaper to use than the ones just cited and, according to a priori tests, looks very promising. We intend to use it and compare the results with some of the models we have already tried. These, more robust, SGS models will be tested as part of our effort to improve our parameterization of the sub-grid-scale processes for large-scale simulations of the ocean mixed-layer.

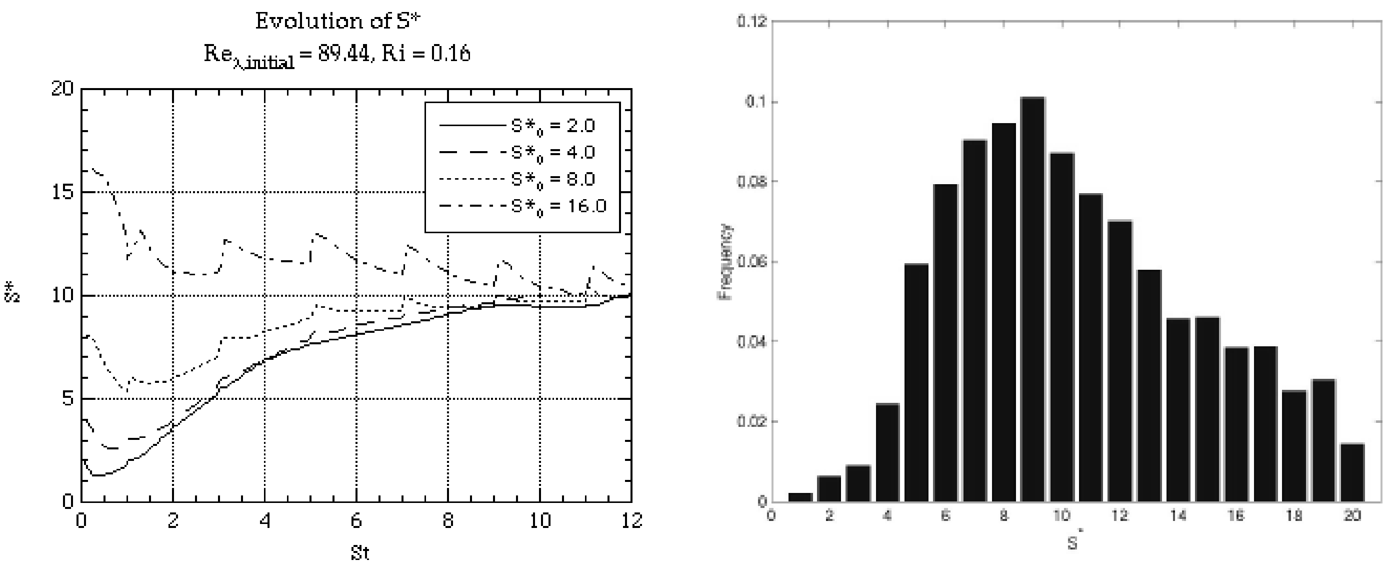
WORK COMPLETED

We are now in the process of implementing a parallelized Navier-Stokes code for solving stratified, turbulent channel flows on an SGI parallel machine using MPI, and by partioning the grid across processors. Some preliminary runs have been done. We have also published the results of Direct Numerical Simulations (DNS) (Shih et al, 2000) of stratified sheared homogeneous turbulence over a wide range of initial dimensionless shear rates and turbulent Reynolds numbers. These simulations were performed to test the published result of Jacobitz et al (1997) that the stationary Richardson number is a function not only of the Reynolds number but also of the dimensionless shear rate. The simulation results were also used to test some new ideas for the scaling of stratified turbulence. We have begun using the results from our previous numerical simulations of stratified sheared homogeneous turbulence (Holt et al., 1992, Shih et al., 2000), stratified channel flows (Garg et al, 2000), and a stratified, turbulent mixing layer (Briggs et al, 199x) to develop modifications to existing turbulence closure schemes such as k-e and Mellor-Yamada for stratified flows. The initial work has focused on finding possible relationships between the constants used in these models and local turbulence parameters such as turbulent Froude number (Fr_t).

RESULTS

Stratified Shear Flows

Over the wide range of Richardson (Ri), dimensionless shear number (S*), and Reynolds (Re) numbers we found the following results:



(a) *(b)*

Figure 1: Evolution of S* obtained from DNS by Shih et al. (2000) shown in (a) and measurements of S* made by Stacey (1996) in a stratified channel flow in San Francisco Bay in (b)

1. At low Reynolds number the stationary Richardson number depends on both the Reynolds number and the dimensionless shear number. At higher Reynolds number, however, we established that the dimensionless shear number (shear rate times turbulent kinetic energy divided by dissipation rate) evolves to a constant (around 10), regardless of its initial value, and that the stationary Richardson number varies only with Reynolds number. This is shown in Figure 1(a) for various initial S*. Stacey (1996) measurements of S* in a stratified channel flow in San Francisco Bay are shown as a pdf in Figure 1(b). As can be seen from this figure the pdf peak is for S* of 10, strongly suggesting that the structure of the turbulence is the same for the DNS and the field experiments. The implication of this for the development of turbulence models is currently being explored.

2. For the high Re equilibrium flows, we found that the turbulent Froude number (Fr_t) is a constant independent of S*. We developed an Fr_t -based scaling which predicts the final value of S* quite well over a range of Re. Based on this, we showed that Fr_t is a more appropriate parameter for describing the state of stratified turbulence than the gradient Richardson number which is more commonly used in turbulence models of stratified flows.

IMPACT/APPLICATIONS

The simulations completed demonstrate the intrinsic value of DNS and LES in that it allows us to calculate each term in a model or parameterization of the extant physics. Evaluation of existing turbulence closure models or commonly used sub-grid-scale parameterizations is therefore a lot more complete than with experiments alone. Our simulations of the channel flows are the first important step in developing a code for studying the evolution of the density structure of the water column in the near-coastal ocean. Once completed this code will be a valuable research tool for use in conjunction with field work currently underway involved in measuring flowfields in the near-coastal ocean.

TRANSITIONS

The numerical data-bases developed have been analyzed by the PI's in other research projects and the data has been used by researchers at other institutions. For example Diamessis and Nomura at UCSD are using the data from the simulations of Shih et al. (2000) to further examine the interaction between vorticity and rate-of-strain in stratified turbulence.

RELATED PROJECTS

Shear Production and Dissipation in a stratified tidal flow - ONR - (Monismith PI). Our field work includes work on stratified tidal flows in which we are making Reynolds stress measurements using broad-band ADCPs (Stacey, 1996).

An Experimental Study of a Breaking Interfacial Wave - NSF- (Koseff PI). In the laboratory we are performing experiments in an attempt to measure the mixing associated with a breaking internal wave at a stratified (two-layer) interface using the wave-generation technique of Rapp and Melville. In this work we are measuring the mixing efficiency associated with such an event

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